Considerations of 2 K Operations

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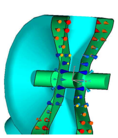
LANL

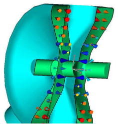
Workshop on the Advanced Design of Spoke Resonators

Los Alamos, NM, USA
October 7 and 8, 2002



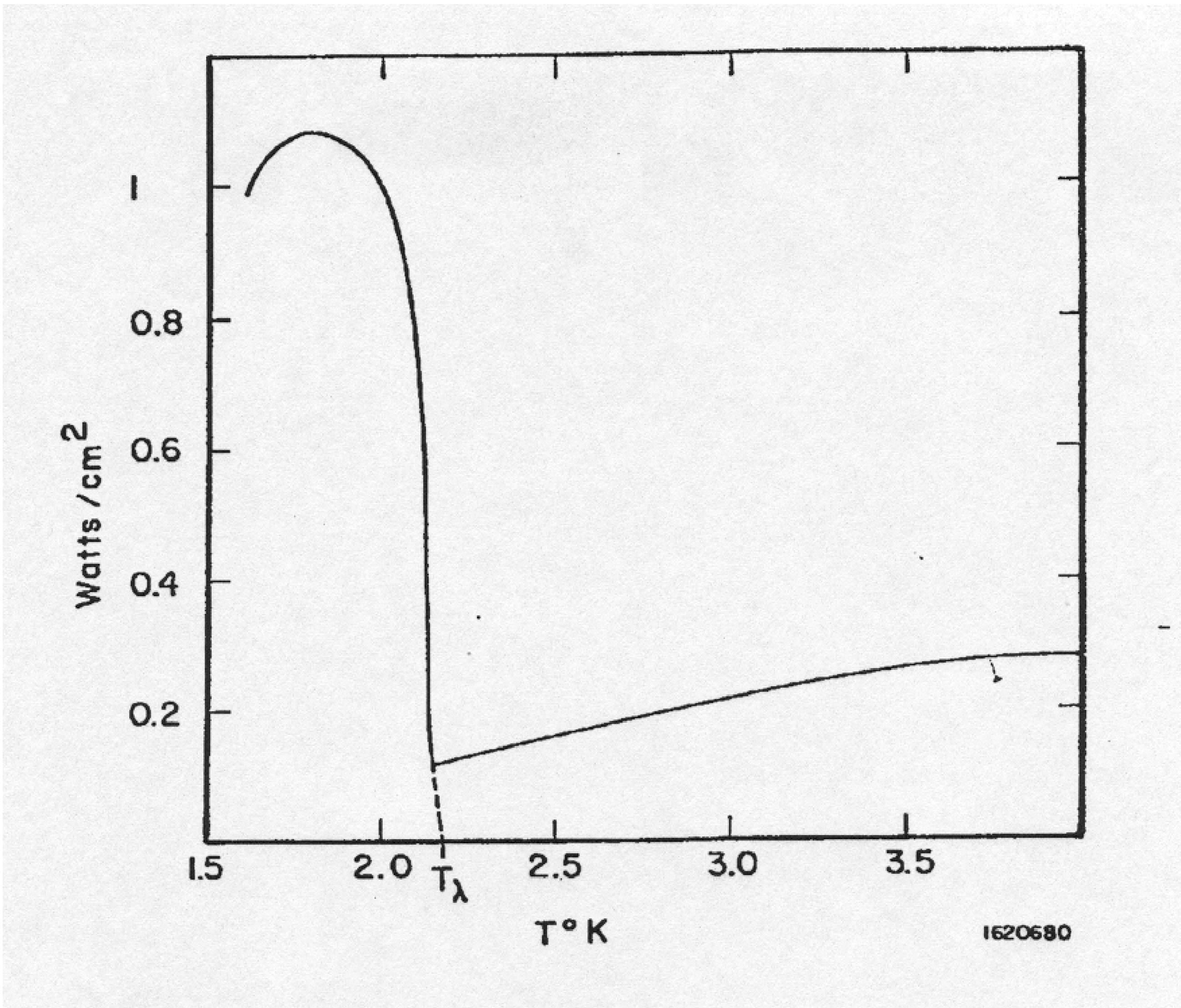
What are the differences between 4 K and 2 K?

- Thermal conductivity of LHe at 2 K is much greater than at 4 K
  - Thermal conductivity of saturated 4 K liquid helium is 1.87E-2 W/mK.
  - Thermal conductivity of 2 K superfluid helium is 1.2E5/q^2 W/mK. (q is heat flux in W/cm^2).
- Cavity surface resistance Rs gets lower with lower temperatures, i.e., BCS resistance decreases exponentially with temperature.



Film boiling limit vs. bath temperature

(H. Padamsee, “Heat transfer and models for beakdown,” CLNS 80/469, July 1980)



The Cavity Surface Resistance, R_s

$$R_s = R_{BCS} + R_{residual}$$

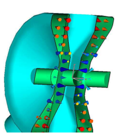
$$R_{BCS} = A \cdot \frac{f^2}{T} \cdot \exp\left(-\frac{\Delta}{k_B T_c} \cdot \frac{T_c}{T} \right)$$

f: Cavity frequency
T: Operation temp.
Δ: Energy gap
T_c: Transition temp, 9.25 K for Nb.

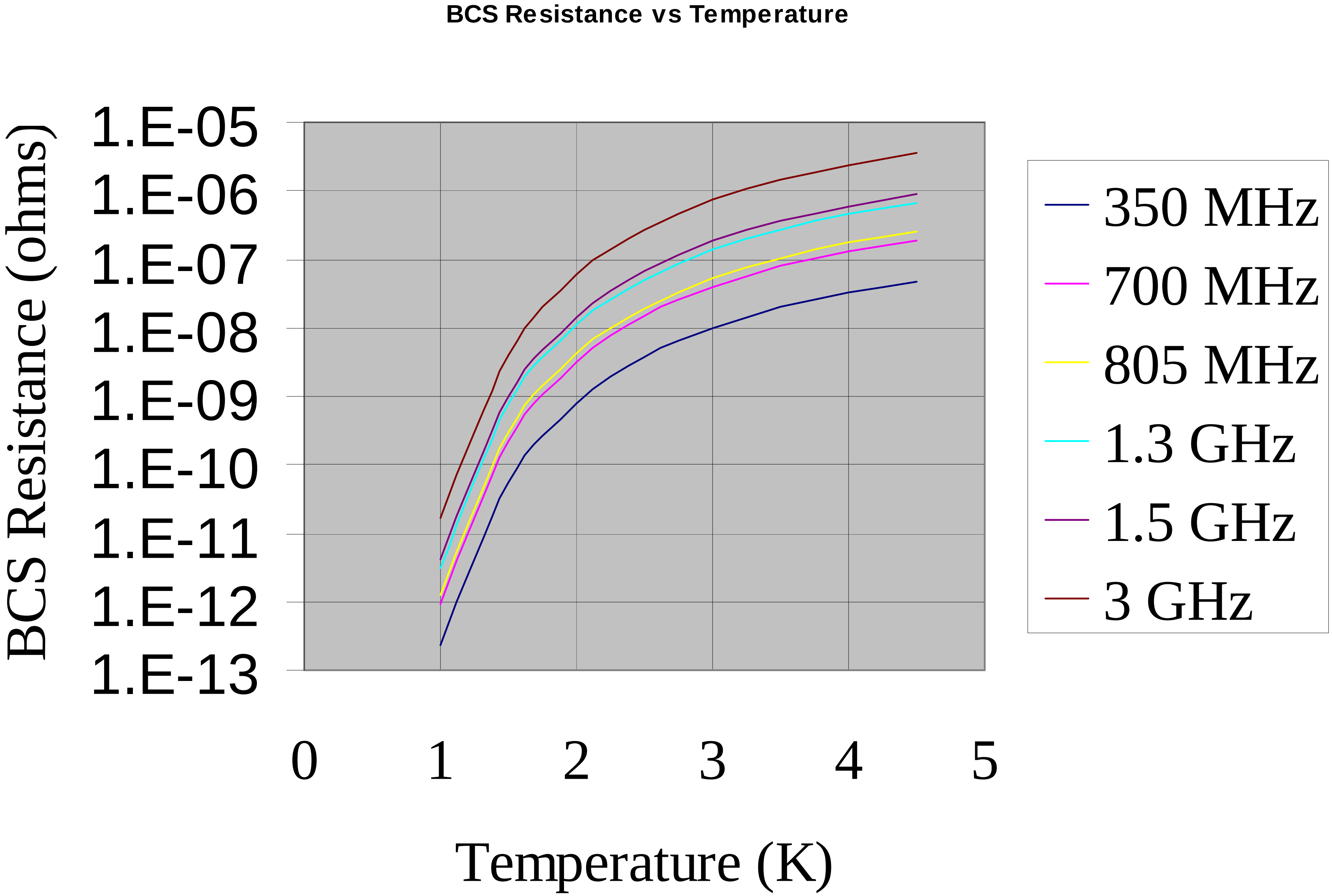
$$R_{BCS}(\mathrm{ohm}) = 2\times10^{-4} \frac{1}{T} \left(\frac{f[\mathrm{GHz}]}{1.5} \right)^2 \exp\left(-\frac{17.67}{T} \right)$$

$$R_{res} = R_{res}(H_{rf}) + R_{fl}(H_{rf}, H_{ext}, T)$$

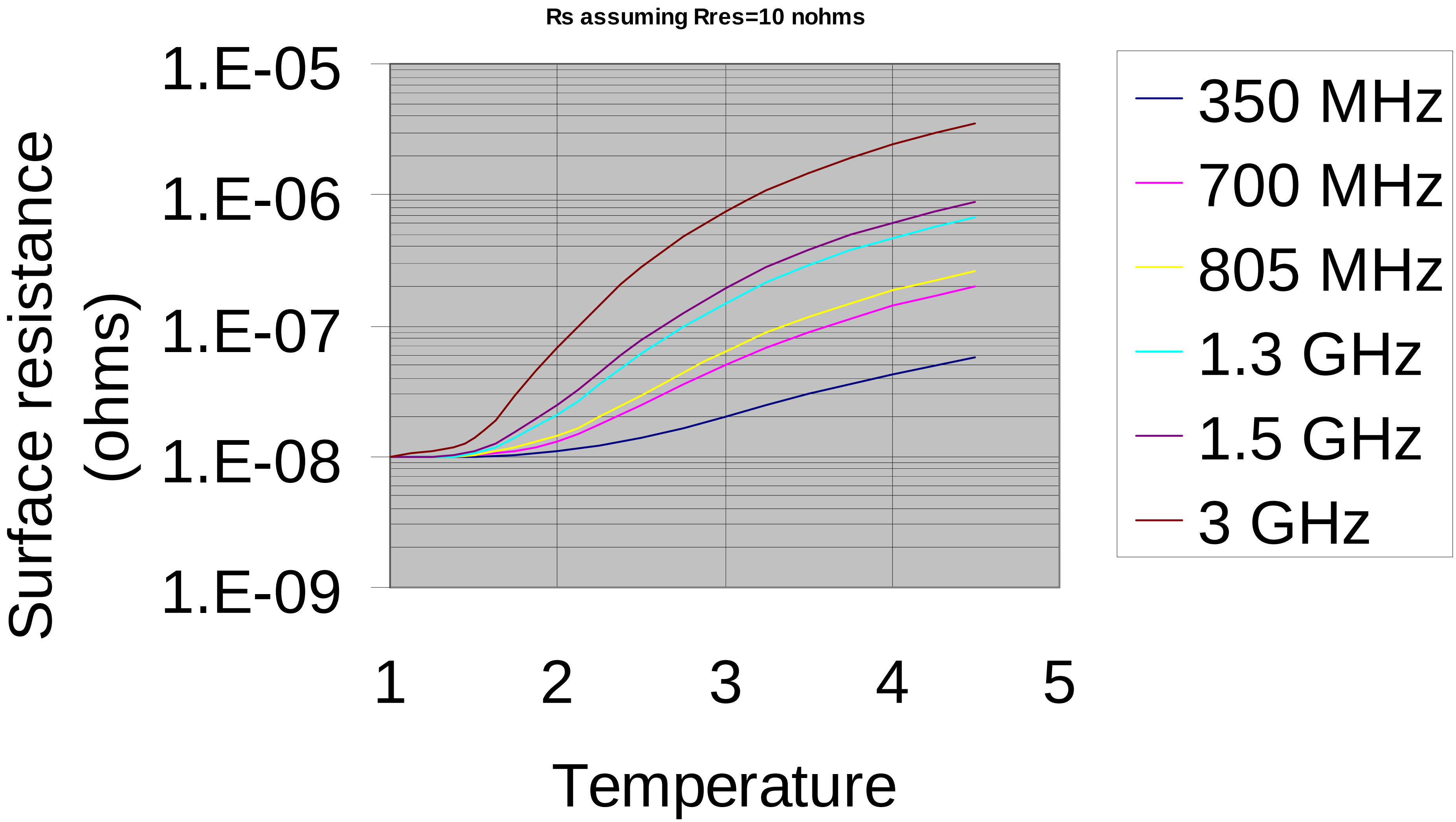
R_{res} = 1 ~ 10 nohms with well prepared surface

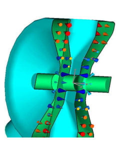


BCS Resistance vs. Temperature

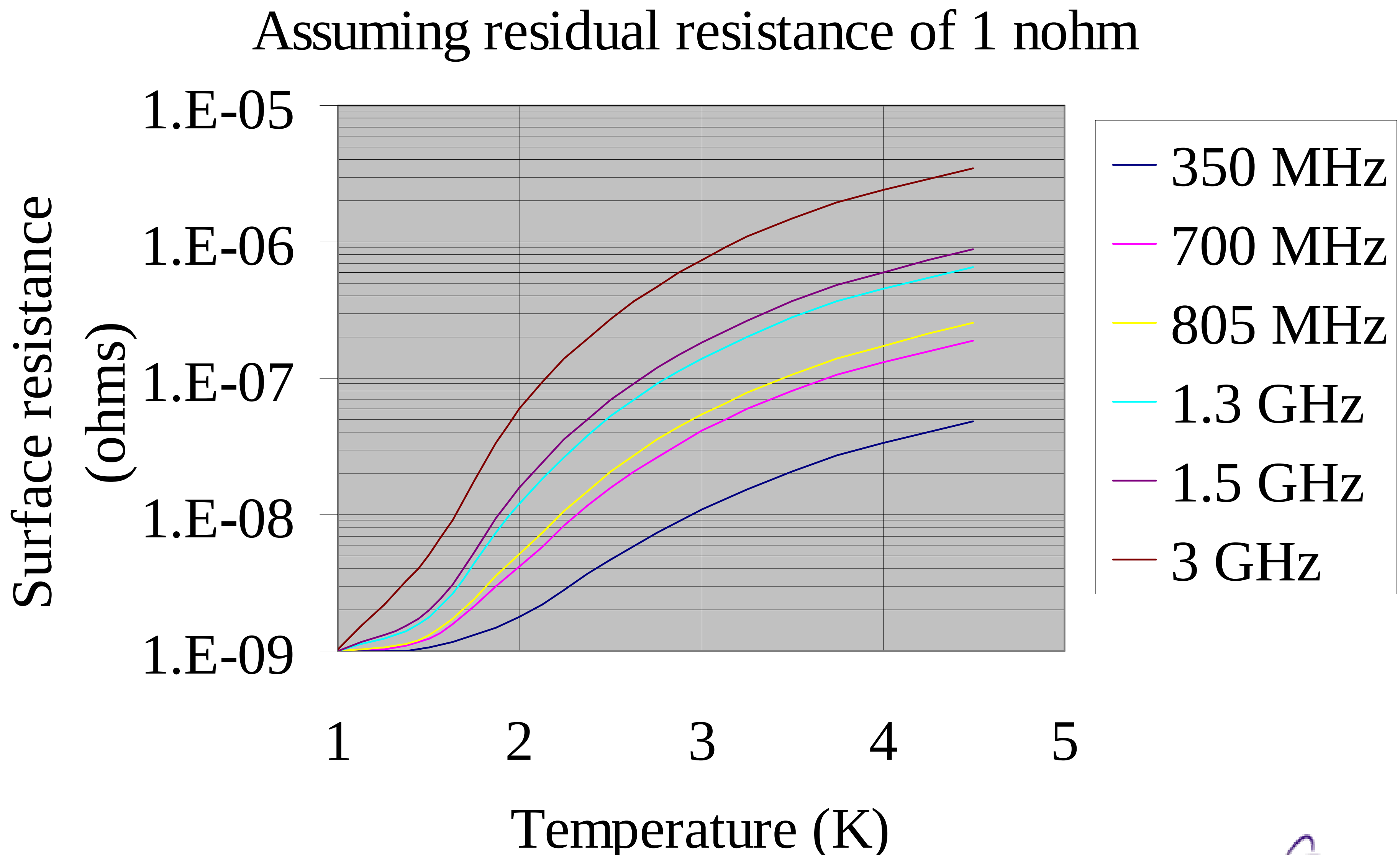


Surface Resistance with R_{res}= 10 nohms

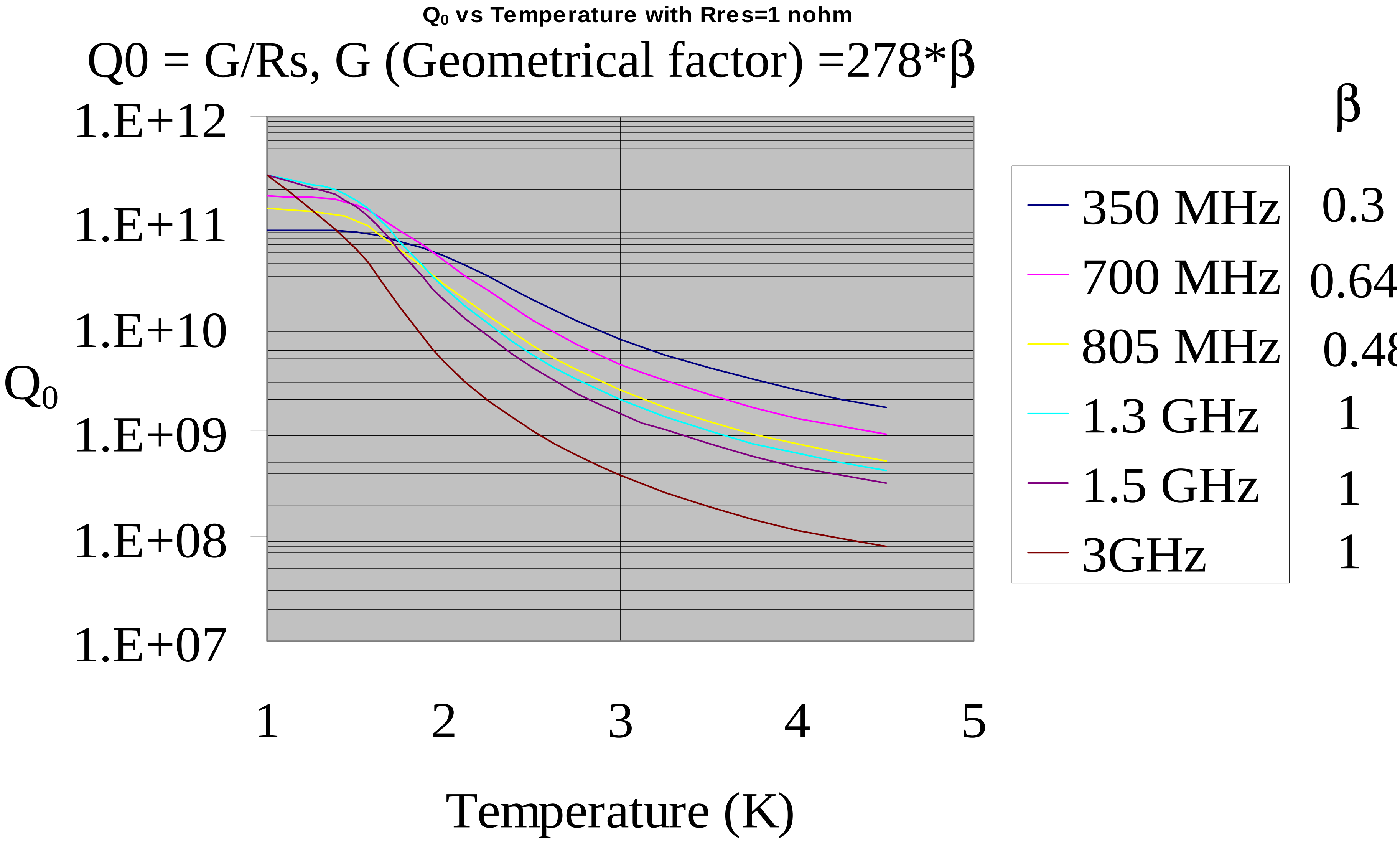




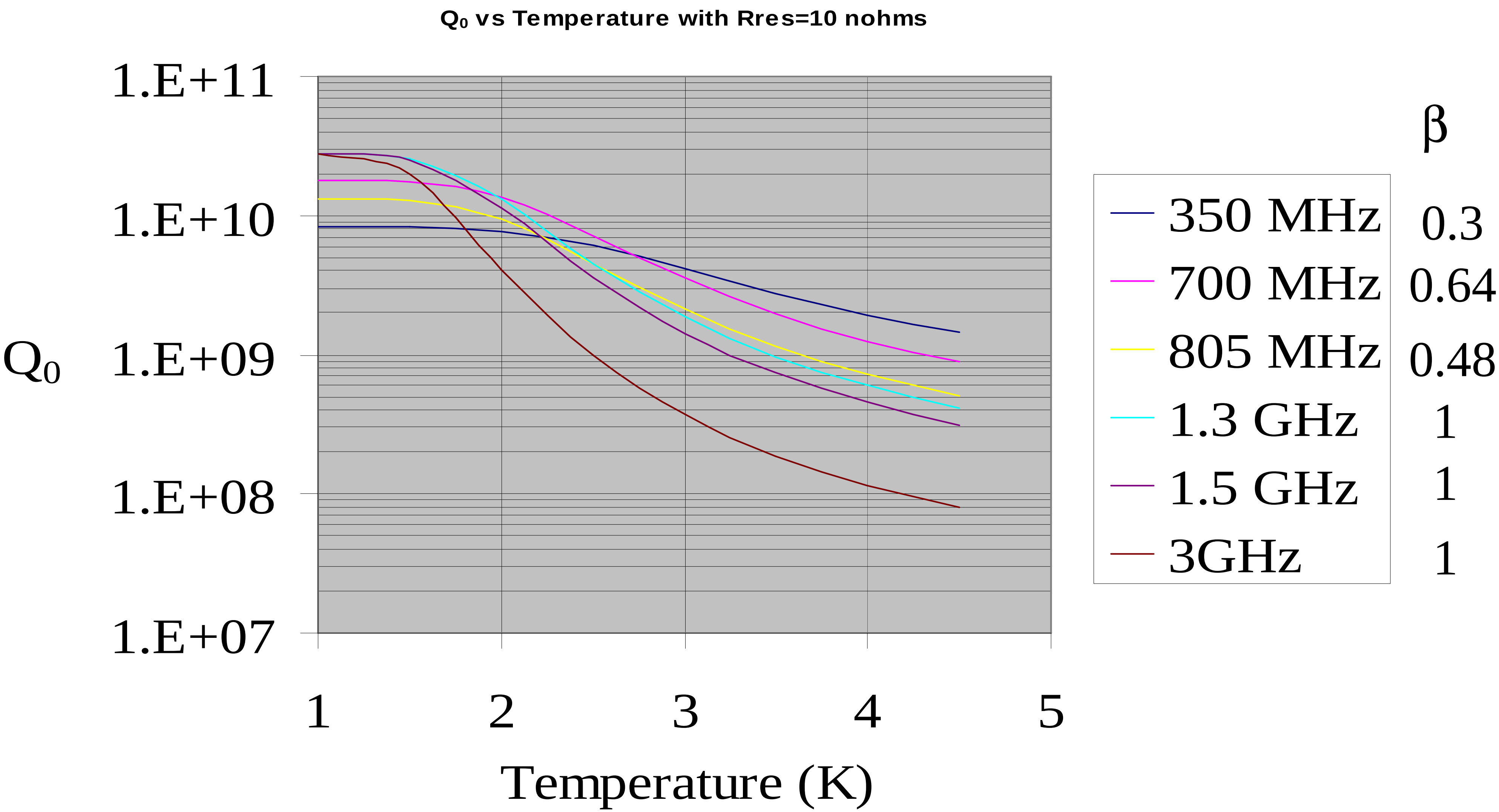
Surface resistance with R_{res}= 1 nohm



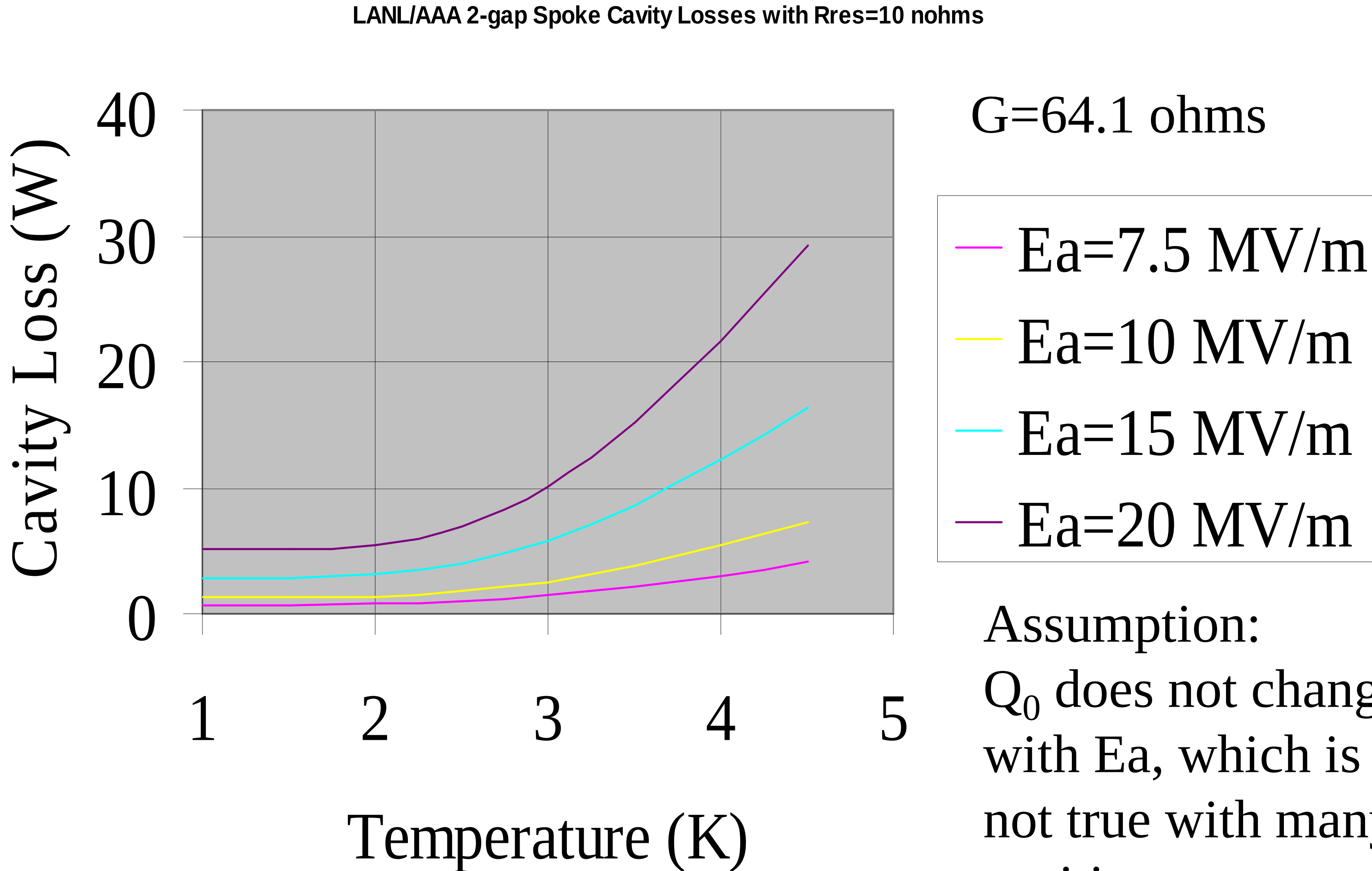
Q_0 vs. Temperature with R_{res} = 1 nohm



Q_0 vs. Temperature with R_{res} = 10 nohms



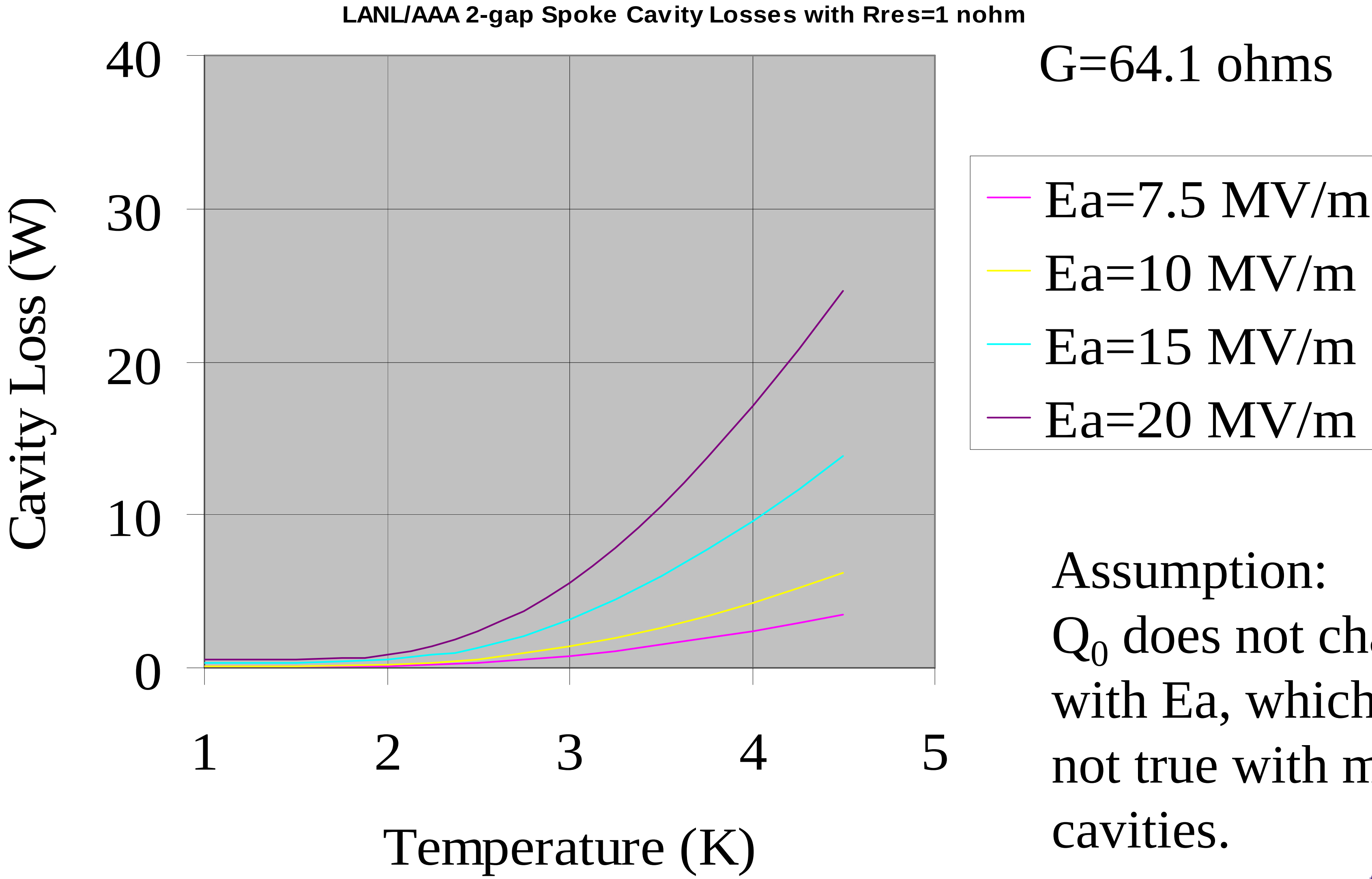
Cavity Loss of LANL/AAA 2-Gap Spoke, R_{res} = 10 nohms



G=64.1 ohms

Assumption:
Q_0 does not change with Ea, which is not true with many cavities.

Cavity Loss of LANL/AAA 2-Gap Spoke, R_{res} = 1 nohm



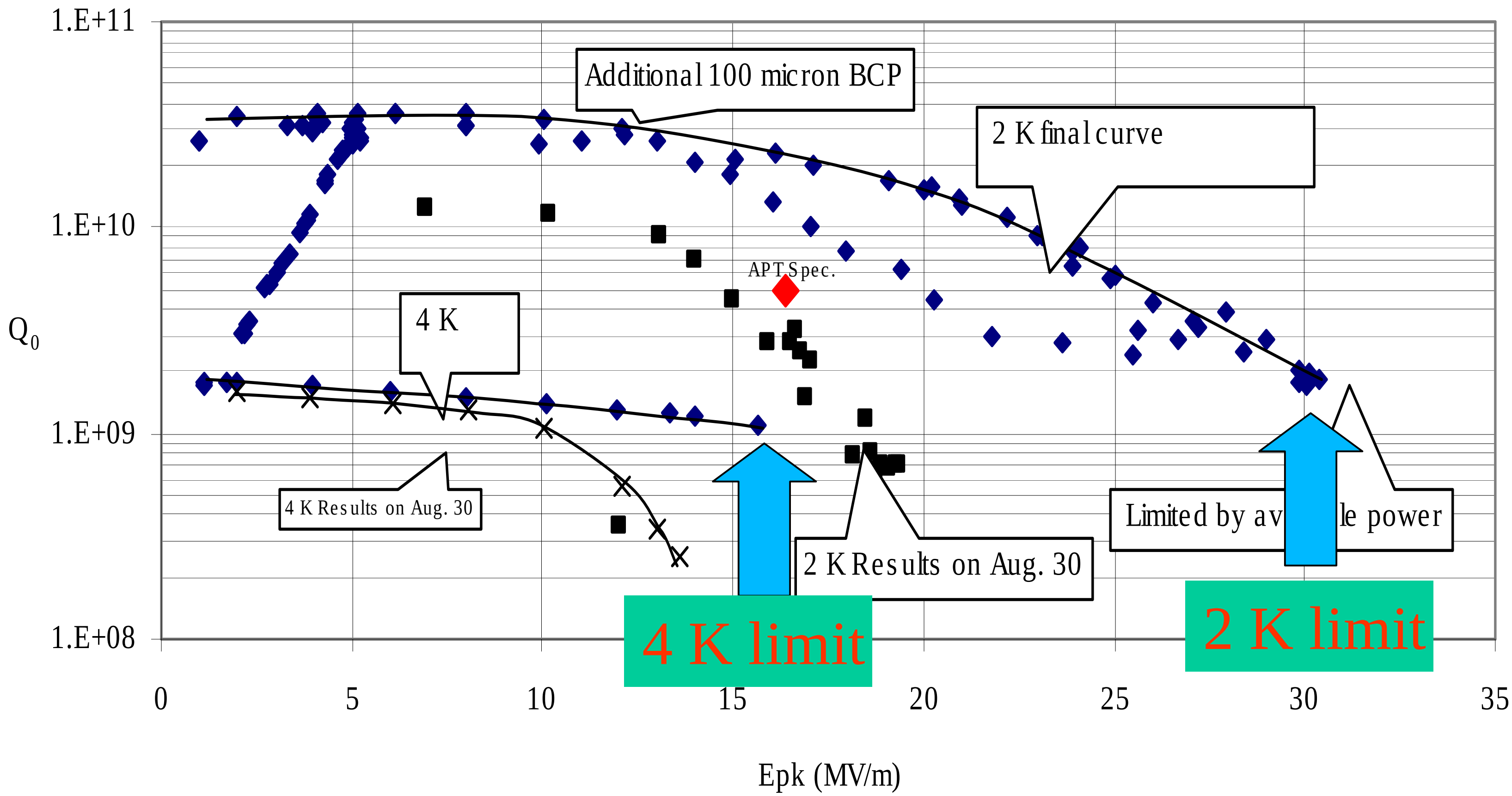
G=64.1 ohms

Assumption:
Q_0 does not change with Ea, which is not true with many cavities.

An Experience with LANL/APT 700-MHz β=0.64 Elliptical Cavity

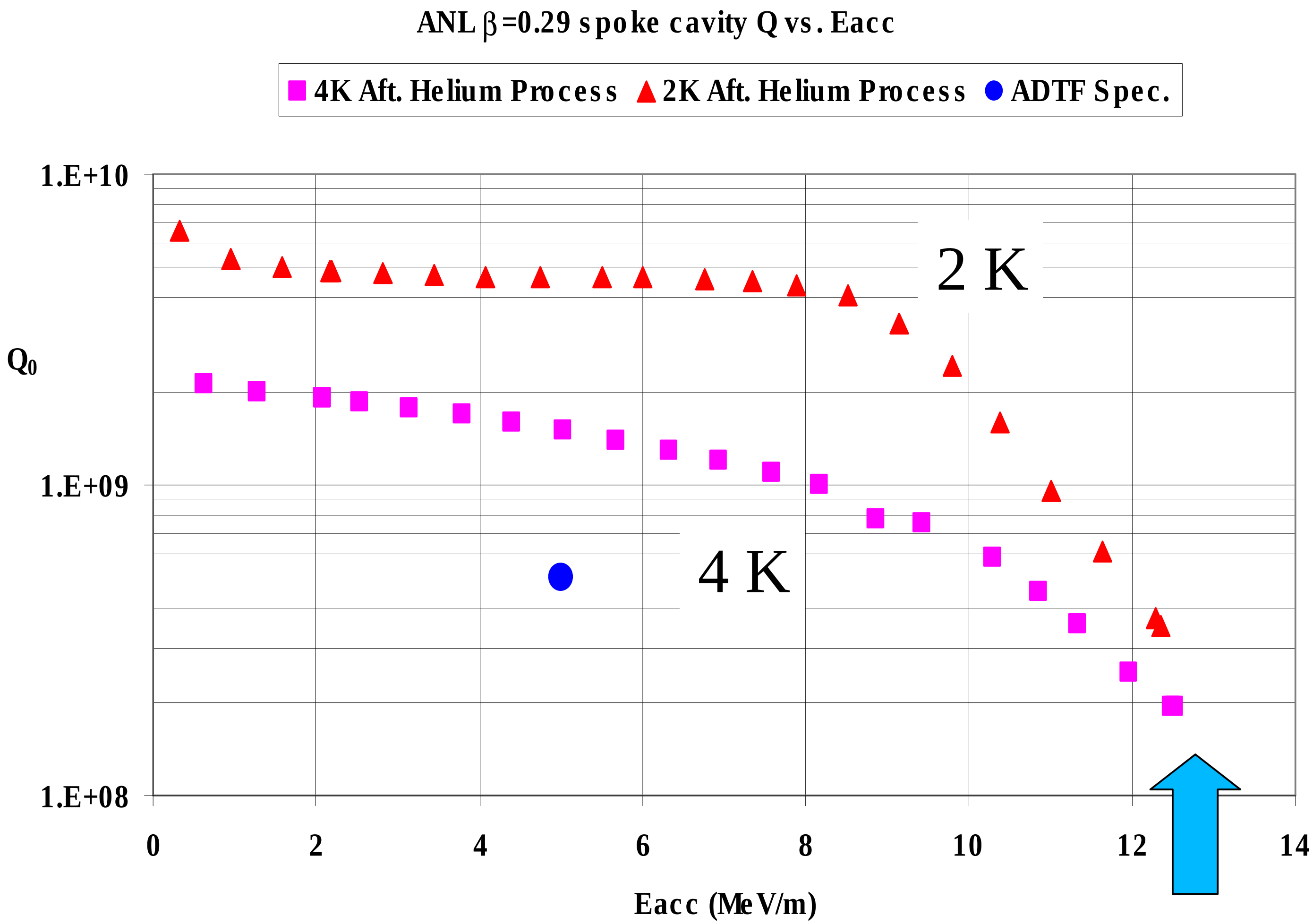
LANL Cavity on 1-18-01 with the data on 8-30-00

There is a defect on the equator weld of middle cell and limited by quencl



•2 K is not always better than 4 K.

An Experience with ANL β=0.29, 340-MHz, 2-Gap Spoke Cavity



4 K and 2 K limits are the same

How About Costs of a Cryogenic Plant at 4.5 K and 2 K?

According to H. Safa’s paper in LINAC98 conference,

$$\boldsymbol{C}_{\boldsymbol{captital}}(\$) = 3000\left(3+\frac{4.5}{\mathrm{T}}\right)\left(\frac{\eta_{4.5\boldsymbol{K}}}{\eta}\mathrm{R}\right)^{0.7}$$

$$\boldsymbol{C}_{\boldsymbol{operation}}(\$/\boldsymbol{year}) \approx 0.35\times \mathrm{P}_{\mathrm{AC}} = 0.35\frac{\mathrm{R}}{\eta}$$

T: operation temperature

R: refrigeration power in W

$\eta_{4.5K}$: overall efficiency at 4.5 K

η: overall efficiency

P_{AC}: AC electric power of the cryogenic plant

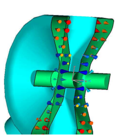
Overall Efficiency of Cryogenic Plant, η

$$\eta = \eta_r \cdot \eta_{Carnot}$$

$$\eta_r = 0.035\,\mathrm{Ln}(\mathrm{R})\tanh\left(\frac{\mathrm{T}}{3}\right)$$

$$\eta_{Carnot} = \frac{\mathrm{T}}{\mathrm{T_a} - \mathrm{T}}$$

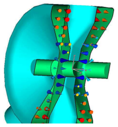
T_a: Room temperature, 310 K is generally taken.



An Example with AAA 600 MeV Nuclear Waste Transmuter

Assumptions:						
Ref. SC Linac Design Parameters,						
Strawman S2 Design 6, R. Garnett, LANSCE-1:01-063						
	β	**f (MHz)**	**Type**	**No. Cavity**	**Ea (MV/m)**	**G (ohms)**
Section 1	0.175	350	2-gap spoke	80	7.5*	64.1
Section 2	0.34	350	3-gap spoke	36	7.5*	94.5*
Section 3	0.48	700	5-cell elliptical	32	7.5*	133*
Section 4	0.64	700	5-cell elliptical	93	7.5*	149

*Modified for simplicity or due to no specific design yet



Los Alamos NATIONAL LABORATORY

An Example with AAA 600 MeV Nuclear Waste Transmuter

Costs in M$			
R_{res}=10 nohms			
Operation temperature	**4.5 K**	**4.5K/2K**	**2K**
Capital cost in sections 1 and 2	19.1	19.1	18.7
Capital cost in sections 3 and 4	268	126	126
Total cryogenic loss	24.6 kW	2.13 kW	1.68 kW
Total capital cost	287	145	145
Total operational cost per year	1.85	0.631	0.625
R_{res}=1 nohm			
Operation temperature	**4.5 K**	**4.5K/2K**	**2K**
Capital cost in sections 1 and 2	16.9	16.9	5.32
Capital cost in sections 3 and 4	259	56.4	56.4
Total cryogenic loss	23.4 kW	0.964 kW	0.516 kW
Total capital cost	276	73.3	61.7
Total operational cost per year	1.77	0.269	0.228

Action Items for Further Study

- **Collect more data on the difference of gradient limitation at 4 K and 2 K**
- **Analyze the loss mechanisms and classify the situations where 2 K operation is advantageous.**
- **Cost analyses of cryogenic plant including static losses, margins and other items.**
- **Analyze further the benefits of 2 K only system as compared to 4.5K/2K system.**
- **How about replacing β=0.48 section with spoke cavities and operate at 4.5 K?**